

THE WORLD OF CHEMISTRY

Program #7

THE PERIODIC TABLE

Producer Doug Bolin

Air Script: October 31, 1988

PRODUCED BY

EDUCATIONAL FILM CENTER

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THE UNIVERSITY OF MARYLAND

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Annenberg/CPB Project Logo and Music

Funder Credits

RH in front of
periodic table

ROALD HOFFMANN (SYNC):

I'd like to show you the most important
piece of equipment that you're likely to
encounter in a chemical laboratory.

How much do you think it'll cost? Was
it invented in the United States and made
in Japan? Are you ready? Let's see.

Here it is. This is it. Not a
superconducting supercollider, is it?
Not a piece of equipment that's worth a
hundred million dollars. Just a piece of
paper, a chart, an idea, a tool for the
mind. This was invented by Mendeleev,
a Russian, 120 years ago. It's called the
periodic table, and it's worth more to
chemists than all of the pieces of
equipment in our laboratories.

SUPER: THE PERIODIC
TABLE

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

MONTAGE: Sunset shots,
close up of experiments,
diamond, heating, boiling,
lightbulb, close ups of
various elements

NARRATOR (MUSIC and NAT
SOUND under):

What are the properties of the substances in the world around us? There are two types of properties. Chemical properties refer to the elements' ability to combine with other elements and form compounds. Physical properties include density, hardness, melting point, boiling point, and conductivity. Each element is different from every other element in its chemical and physical properties. This uniqueness can be traced to the atomic structure of the element. But some groups of elements also share common properties that vary systematically and predictably. These common properties are the basis of the modern periodic table.

GRAPHIC: The periodic
table: symbols for the
elements

NARRATOR (MUSIC under):

There are 109 elements in it. 88 occur naturally. The other 21 are man-made or artificial elements. For centuries, Latin was the common language of science, so many elements have Latin names. (cont.)

NARRATOR cont:

For instance, iron was ferrum, so its abbreviation became "Fe". Gold was Aurum, Latin for "shining dog," so it became "Au". Madame Curie discovered an element and named it after her native Poland, "polonium." And more recently discovered elements have been named after famous people, such as Einsteinium, named for Albert Einstein, and Nobelium, named for the man who established the Nobel prize, Alfred Nobel. Besides a symbol for the element's name, in this case helium, each box also contains some important numbers. Notice the number below the He symbol. This is the atomic mass of the element, the total mass of the protons and neutrons.

GRAPHIC: Isotope definition

NARRATOR (MUSIC under):

All helium nuclei contain two protons. However, the number of neutrons may vary. For example, there's a rare form of helium which has only one neutron in the nucleus. The two varieties of the same element are called isotopes.

GRAPHIC: The periodic
table: atomic mass and
number

NARRATOR (MUSIC under):

The atomic mass of an element is the weighted average of the masses of the isotopes in the naturally occurring element. The number over the symbol in each box is the atomic number of the element, the number of protons in each nucleus.

DS in lab

DON SHOWALTER (SYNC):

An atomic number is what determines an element's position in the table. The elements in the table are arranged in order of ascending atomic numbers, as you go from left to right. Here we have hydrogen number 1, way over here, helium number 2, then lithium 3, beryllium 4, boron 5, and so on across to neon 10, back to sodium 11, and magnesium 12, and so on, left to right. Now there's another facet to the table. Because of the way it's laid out, each element is a member of a group that goes up and down the table, and a period that goes across the table. For example, potassium, it is a member of this group, and it is a member of this period.

GRAPHIC: The periodic
table: periods

NARRATOR (MUSIC under):

There are seven horizontal periods,
running from left to right. Each one has
been assigned a number, which is placed
at the left of the period. Fourteen of the
elements in periods 6 and 7 are pulled
out of their place and laid out below. If
they were placed in the table, it would
look like this. So it makes it much
easier to arrange the table if they are at
the bottom.

DS in lab

DON SHOWALTER (SYNC):

There are also 18 vertical columns,
called groups or families. Each group is
designated by a number and a letter,
which is placed at the top of the column.

GRAPHIC: The periodic
table: groups

NARRATOR (MUSIC under):

Elements within a family all have
similar properties. To demonstrate this,
let's look at one family on the far right
of the periodic table, the noble gases.

DS in gymnasium

SUPERS: He, Ne, Ar,
Kr, Xe

DON SHOWALTER (SYNC):

These balloons contain the first five
noble gases. We have helium, neon,
argon, krypton, and xenon. (cont.)

DON SHOWALTER cont:

Now, we're missing radon because it's radioactive. We're all familiar with helium. It's used in balloons and blimps. The rest are used to fill various light bulbs and lamps. But what are some of the properties that they have in common? Well, they're odorless, and they're colorless, and they're all quite unreactive. And as you go down in the family, each one gets heavier than the previous one. Let me show you what I mean. This is helium. Here it goes. This is neon. It's somewhat lighter than air. There it goes. Now, argon and krypton are both heavier than air, and xenon is the heaviest of the ones we've seen. It's the proverbial lead balloon.

GRAPHIC: The
periodic table

NARRATOR (MUSIC under):

You can begin to see the different types of information that can be derived from the periodic table. But how do chemists use the table in their work?

MONTAGE: Shots of
glass making,
glassware

NARRATOR (MUSIC and NAT
SOUND under):

Glass making is one example. At one time in the ancient world, glass was so rare that it was prized more highly than jewels or gold. (cont.)

NARRATOR cont:

But as we mastered the techniques of glass working, glass became a commonplace necessity. The types of glass multiplied tremendously. So that today glass comes in many forms and colors. Artists use it to create new and intriguing constructions. Craftsmen mold it by hand into the elegant forms of Steuben crystal. And factories manufacture glass for countless everyday uses. Basically, different types of glass are made by mixing silicon dioxide, sand, with different metal oxides, then melting them together. The choice of the oxides, which determines the characteristics of the glass, is guided by the periodic table. Dr. Gerry Fine is a glass chemist at the Corning Glass Works in Corning, New York.

INTERVIEW: Dr. Gerry
Fine, glass chemist, Corning
Glass Works, Corning,
New York

SUPER: Gerry Fine

DR. GERRY FINE (SYNC):

I cannot imagine working without the periodic table, because scientists are interested in looking for systematic relationships between different substances and between different elements. (cont.)

DR. GERRY FINE cont:

The periodic table is a simple way of looking up and finding systematic relationships between different elements that we can understand at a very simple level.

Shots of glass making,
periodic table graphic

NARRATOR (MUSIC and NAT
SOUND under):

In the glass research center at Corning, thousands of samples are poured each year as new types of glass are developed and perfected. One group of elements frequently used to make glass is on the far left of the periodic table, the alkali metals. By mixing in different alkali metals, glass with different characteristics can be produced. So understanding their variations in behavior is important to glass makers, and, indeed, to all chemists.

DS in lab

DON SHOWALTER (SYNC):

We call this family the alkali metals. They make up Group 1 in the periodic table. The first element is lithium, and then there's sodium, and potassium. Down here is rubidium, and this one is cesium. And do you notice anything that they all have in common? You probably see that they're all stored in very unusual ways. (cont.)

DON SHOWALTER cont:

The reason we do this is because they're all highly reactive. I have here three containers of just water. I'm gonna take a piece of this lithium and put it into the water. And watch what happens, how it starts to fizz a little bit. The fizzing now is the reaction of lithium with the water to produce hydrogen gas. Let's try the sodium. I'll get a small piece of that, not too big, because we don't want the reaction to be too violent. Oh, that reacts much faster, doesn't it? See the sodium bouncing around there, again fizzing, giving off that hydrogen gas. Okay. Let's try potassium, the most reactive of the three. I'll get a small piece of that and put it into the water. Wow! That really reacted violently. Did you see the immediate reaction of the potassium? Again, it's formed that hydrogen gas and the hydrogen gas was ignited.

Shots of alkali metals,
glass strength test

NARRATOR (MUSIC under):

So the alkaline metals all have similar chemical properties, but they also vary systematically. As you go from the top to the bottom of the column, the atoms of each element become larger. Chemists can use this characteristic to increase the strength of their glass.

GRAPHIC: The periodic
table (size chart)

NARRATOR (MUSIC under):

The size of an atom increases as we go down any column. In the alkali metal group, the atomic size increases from lithium, to sodium, to potassium, and so on. But as we move across a period, starting with an alkali metal, the size of the atom gets smaller and smaller until we get to a new period. Here we see a jump in atomic size in the next alkali metal, and again a decrease along the period. This pattern repeats itself throughout the table and is called periodicity.

INTERVIEW: Dr. Gerry
Fine cont.

DR. GERRY FINE (SYNC):

Everyone is aware that glass tends to be a brittle material. If you've ever thrown a baseball through a window, you know that the glass breaks quite readily.

However, there are ways of taking that simple window glass, which is made of sodium, calcium, and silicon, and treating the glass to make it strong. One way that we do that is by use of the periodic table. If we take that glass that contains sodium and substitute potassium in the surface for the sodium, or substitute an element that behaves basically in the same way, but is slightly larger, we can enhance the strength of that glass and make strong glass.

Glass strength
demonstration

NARRATOR (NAT SOUND under):

The results of this process are quite easy to demonstrate. If a steel ball bearing is dropped from one foot onto glass made with the alkali metal, sodium, watch what happens. The sodium-based glass shatters completely. Now watch what happens if the same ball bearing is dropped on a piece of glass where potassium has been substituted for sodium. This time the ball will be dropped from 20 feet.

INTERVIEW: Dr. Gerry
Fine cont.

DR. GERRY FINE (SYNC):

The way we do that is by taking the glass, which contains sodium, and dipping it in a bath containing molten potassium. What happens is the molten potassium substitutes for the sodium in the glass on the surface of the glass. Because, from the periodic table, we can tell that potassium is larger than sodium, the potassium atom literally stuffs the surface of that glass.

GRAPHIC: The periodic
table, archival photographs
of Dmitri Mendeleev

NARRATOR (MUSIC under):

The predictive ability of the period table was first demonstrated by a Russian chemist, Dmitri Mendeleev. (cont.)

NARRATOR cont:

One hundred years ago, he developed the predecessor of our modern table. Mendeleev's table included all the elements then known and was consistent with their varying properties. For three undiscovered elements, he left blank spaces, predicting that they did exist and that their properties would be consistent with their position in the table. For his time, it was an amazing hypothesis. One position that he left blank was this one, for gallium. Based on the properties of the two neighboring elements, aluminum and indium, Mendeleev was able to predict some of the properties of gallium. He was also able to predict two other elements, germanium and scandium. When the elements were discovered and their properties measured, Mendeleev's predictions were found to be remarkably accurate.

Archival photographs of
Glenn Seaborg

NARRATOR (MUSIC under):

In this century, another chemist, an American, rearranged the structure of the table based on the properties of elements that he, himself, had discovered. His name is Glenn Seaborg.

GRAPHIC: The periodic table

NARRATOR (MUSIC under):

In 1944, the periodic table didn't look like it does today. The periods and groups were laid out differently.

INTERVIEW: Dr. Glenn Seaborg

SUPER: Glenn Seaborg

DR. GLENN SEABORG (SYNC):

Back in the days of Mendeleev, and actually extending into the 1930s, the heaviest elements, thorium, protactinium, and uranium, were put into the periodic table up in the body of the periodic table under hafnium and tantalum and tungsten, and it was my idea, in 1944, while I was working on the -- at the metallurgical laboratory in Chicago on the Manhattan atomic bomb project, that these might be misplaced, and that they might be the first three members of the actinide series. And then I boldly, and against the advice of some of my eminent inorganic chemist friends, plucked those out of the body of the periodic table and put them in the row below, and then continued that with 93, 94, and so forth, up to 103.

Archival photographs of
Glenn Seaborg

NARRATOR:

The idea to rearrange the table occurred to Seaborg late one Friday afternoon. He was drafting a classified report for a seminar the following Monday. And he decided to include this idea in his report.

INTERVIEW: Dr. Glenn
Seaborg cont.

DR. GLENN SEABORG (SYNC):

I presented this at that Monday seminar and, you know, it went over like a lead balloon, you know, the idea that one would be brash enough to change the periodic table after all these years, in this fashion, when, you know, everybody felt that thorium, protactinium and uranium should be in those sacrosanct [sic] positions up in the body of the periodic table under hafnium, tantalum, and tungsten.

Archival photographs of
Glenn Seaborg

NARRATOR:

His discoveries of the new elements remained classified until after World War II. When he was able to publish, he incorporated his new arrangement of the periodic table.

INTERVIEW: Dr. Glenn
Seaborg cont.

DR. GLENN SEABORG (SYNC):
I showed this periodic table to some of my friends, the most eminent inorganic chemists in the world, and told them that I planned to publish it, and they said, "Don't do it, Glenn. It's wrong. It will ruin your scientific reputation." Well, I'm fond of saying that I had an advantage, I didn't have any scientific reputation at that time, so I went ahead and published it.

Archival photographs of
Glenn Seaborg, Nobel
Prize

NARRATOR:
Seaborg's new arrangement enabled him to predict the properties of still more elements. His ideas were later verified when the elements were produced artificially. Seaborg was awarded the Nobel prize in chemistry in 1951.

GRAPHIC: The periodic
table

NARRATOR (MUSIC under):
His rearrangement is our modern periodic table. And what ultimately determines the position of an element in this modern table is the way the electrons are arranged in the energy levels of the atom.

Image of atom

GRAPHIC: Energy level
diagrams for elements

NARRATOR (MUSIC under):

As we move through the table and the number of electrons in an atom increases, the energy level diagrams contain more and more levels and sublevels. Both the number and types of electron clouds increase in complexity. For example, this is the energy level diagram for hydrogens, one electron in an s-cloud called the 1s. Lithium's three electrons are diagrammed like this, two electrons in the 1s-cloud. Each cloud can contain two electrons. Then the third electron is in another cloud, an s-cloud at the second level. Let's move forward to sodium and look at an energy diagram for its 11 electrons. Its first two electrons are in the cloud at the 1s level. Its next two electrons are in an s-cloud at the second level. This is actually only the first of two sublevels at the second level. So it's called the 2s sublevel. The next 6 electrons of sodium are in the other sublevel, called the 2p sublevel. Notice the number of clouds in the 2p sublevel. There are three p-shaped clouds in it. Each of these clouds contains two electrons. Where does sodium's 11th electron go? As we move higher on this energy diagram, we encounter the first sublevel of level 3, the 3s. It has only one s orbital in it. Sodium's 11th electron goes here. (cont.)

NARRATOR cont:

When chemists diagram energy levels of electrons within an atom, they replace the figures of the clouds or orbitals with blank lines. Arrows are used to indicate the presence of electrons in each orbital. This is the diagram for sodium's 11 electrons. Sodium is the second alkali metal. Note that it has only one electron in its outer orbital, the 3s. This is the diagram for lithium, the first alkali metal. Look at its highest energy level. Once again, it is only half-filled with only one electron in the 2s sublevel. The similarities in properties of lithium and sodium, and, indeed, all the alkali metals, are due to the similarities in their outer electron structure. The outer electrons in any atom are called its valence electrons. The noble gases are another example of a similarity in outer electron structure. They have a filled s or p sublevel, a very stable arrangement. Next to them is an important group called the halogens. They are all missing an electron from an almost-filled sublevel, which makes them very reactive. Now, as the number of electrons in an atom increases, what are the rules these electrons follow in filling different sublevels and orbitals? To find out,

DS on school playing
field

NARRATOR:

Don Showalter went to St. Albans
School on the grounds of the National
Cathedral in Washington, D.C.

DON SHOWALTER (SYNC):

We're out here today to show you how
the electrons fill up the various energy
levels that you just saw on that diagram.
And to help us out, we have these 11
baseball players.

TEAM

Right, coach!

DON SHOWALTER (SYNC):

These baseball players are now gonna
represent electrons, and we're gonna
have an electron practice. They're
gonna practice the rules that chemists
use to fill the various energy levels.
Now, here's the ground rules. These
bleachers represent the various energy
levels, the lowest one being the 1s,
colored blue.

SUPER: 1s

TEAM

1s!

DON SHOWALTER (SYNC):

The next energy level is the 2s. It's
colored green.

SUPER: 1s, 2s

TEAM
2s!

DON SHOWALTER (SYNC):
Alright! Now, the 2p has three
sublevels, and it's colored red.

SUPER: 1s, 2s, 2p

TEAM
2p with three sublevels!

DON SHOWALTER (SYNC):
Good. And we've got the highest energy
level is the 3s, and it's colored yellow.

SUPER: 1s, 2s, 2p, 3s

TEAM
3s!

DON SHOWALTER (SYNC):
Alright. Now, there are three basic
rules that we have to follow. Rule No.
1: Electrons fill lowest energy level
first.

TEAM
Electrons fill the lowest energy level
first!

SUPER: Electrons fill the
lowest energy level first.

DON SHOWALTER (SYNC):
Okay. Here's Rule No. 2: No more
than two electrons in any one orbital.

TEAM
No more than two electrons in one
orbital!

SUPER: No more than two electrons in one orbital.

DON SHOWALTER (SYNC):
Beautiful. Here's Rule No. 3: If you have more than one orbital in a sublevel,

TEAM
If we have more than one orbital in a sublevel,

SUPER: If we have more than one orbital in a sublevel,

DON SHOWALTER (SYNC):
one electron in each orbital before you double up.

TEAM
one electron in each orbital before you double up.

SUPER: one electron in each orbital before you double up.

DON SHOWALTER (SYNC):
Great. Have you got it?

TEAM
Yes coach!

DON SHOWALTER (SYNC):
All right. Let's get energized. The first element is hydrogen. Go!

NARRATOR:
Hydrogen has one electron, so it goes in the lowest energy level available, the 1s.

DON SHOWALTER (SYNC):

Now we're gonna skip to nitrogen. Go!

NARRATOR:

Nitrogen has 7 electrons. The first four fill up the 1s and the 2s. But what about the next three? One goes in each of the three 2p orbitals.

DON SHOWALTER (SYNC):

Now we'll skip ahead to sodium. Are you ready, team?

TEAM

Yes coach!

DON SHOWALTER (SYNC):

Go!

NARRATOR:

Sodium has 11 electrons. The first 4 go into the 1s and the 2s. The next three go into each of the 2p orbitals. Then numbers 8, 9, and 10 go in. Finally, the 11th electron goes into the 3s sublevel.

DON SHOWALTER (SYNC):

And that's the way the electrons fill the energy levels. Right, team?

TEAM

Right coach!

Shots of x-ray
fluorescence

NARRATOR (NAT SOUND under):
Scientists at the Smithsonian Museum
have applied a technique that uses
information about the energy levels of
different atoms to study works of art.
This technique analyzes the elements in
different pigments and is called x-ray
fluorescence. Dr. Jackie Olin is a
chemist at the Smithsonian.

INTERVIEW: Dr. Jackie
Olin, chemist, Smithsonian
Institution

SUPER: Jacqueline Olin

DR. JACKIE OLIN (SYNC):
If, for example, you were to know an
artist's work so very, very well that you
knew that that particular artist never
used a particular pigment in all the
paintings that have been studied, and
there's a painting in question, one might
analyze a painting to determine whether
or not that pigment, a pigment that is not
characteristic of that artist, is present.

Still photograph
of painting

NARRATOR (NAT SOUND under):
X-ray fluorescence involves bombarding
the atoms in the painting with x-rays,
causing them to eject an electron. To
see exactly how this happens, let's return
to the electron team.

"Electron Team"

NARRATOR (NAT SOUND under):
Here are the electrons in their energy levels for the element sodium. As an x-ray enters the atom, it knocks out an electron in the lowest orbital, the 1s. When this happens, some of the electrons in higher energy levels fall to lower energy levels, filling the gaps. As the electrons cascade down to lower energy levels, they give off an x-ray pattern that is characteristic of each element.

Instruments analyzing
x-rays

NARRATOR (NAT SOUND under):
Instruments analyze these x-rays and identify what element is present.

INTERVIEW: Dr. Jackie
Olin cont.

DR. JACKIE OLIN (SYNC/VO):
It's very nice to be able to quickly and easily find out what some of the elements are that are in the painting, because we have looked at the painting in terms of the colors we see, and we'll be interested to know that blue is a copper-containing blue or a cobalt-containing blue, and that can be done readily by using x-ray fluorescence to identify the elements present in that area. (cont.)

Analyzing artwork

JACKIE OLIN cont:

So it's a nice technique for
nondestructively and quickly identifying
some of the elements present in the
painting.

SUPER: THE PERIODIC
TABLE

MONTAGE: Periodic table
graphic, elements, program
demonstrations

NARRATOR (MUSIC under):

To review: The elements in the periodic
table are arranged in serial order
according to their atomic number. The
rows are called periods, and the columns
are called groups. The size of the atoms
increases as we go down in a group and
decreases as we go across any period.
This is an example of a periodic
property. Elements in any group have
similar arrangements of electrons in
their energy levels. Therefore, they
have similar chemical properties.

RH in front of
periodic table

ROALD HOFFMANN (SYNC):

You can see right away that a given
electronic configuration implies similar
properties. For instance, the alkali
metals, with their 1 electron in the s
subshell, they all readily give up that
electron, and no more than one electron.
(cont.)

ROALD HOFFMANN cont:

And all of the halogens, on the other side of the periodic table, with their missing electron and a p subshell, readily accept such an electron. One might ask, why do we concentrate on the outermost electrons and not all the other ones. It's because the outermost electrons are at highest energy, the furthest away from the nucleus. In them is chemistry.

Credits, Closing Montage, Closing Music

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